



The first cultivated meat burger was created by Dr. Mark Post and his team at Maastricht University in the Netherlands. At an event on August 5, 2013, attended by 200 journalists and academics, the cultured beef burger was cooked and tasted live. The burger was made from over 20,000 strands of muscle tissue grown from cow stem cells. It took about two years to develop and cost around \$330,000. *Photo: Mosa Meat*

# Biomass hype or reality?

## Cultivated meat faces hurdles amidst technological promise

As the world seeks alternatives to conventional livestock farming, innovative food technologies like molecular agriculture, regenerative agriculture, and precision fermentation hold promise. However, the journey towards cultivated meat faces a reality check as challenges mount against lofty expectations. Despite significant investments and scientific advancements, the commercialization of cultivated meat remains elusive, raising questions about its viability in meeting global food demands sustainably.

By Henk Hoogenkamp

Innovative food technologies such as molecular agriculture, regenerative agriculture, and precision fermentation have a good chance of becoming a pillar for meeting the growing demand for cultivated meat and fish without further contributing to ecological and environmental degradation.

Splashy headlines overshadow inconvenient truths that apply to

the future of food availability embedded in climate change and how humankind interacts with the planet. If going to market for alternative proteins is unsuccessful, the Paris Climate Agreement goals are probably impossible to achieve. Yet, like with most other transformative changes, there are always unforeseen developments in which reality turns out to be different from the initial idea.

Companies engaged in the research and production of cell-cultivated meat like to portray the dependence on intensive animal agriculture as a broken system that negatively impacts the environment, causes animal suffering, and denigrates human health. However, to achieve the next agricultural revolution, including solving complex bioengineering, economic and legislative challenges, full consumer acceptance, trust, and support will be paramount to the transformation's success.

The finite amount of agricultural land and the availability of

clean water, combined with resource depletion, will force government policymakers to rebalance diets towards more plant-based foods. In other words, they will accept the need to reduce the consumption of foods with higher environmental impact, such as slaughtered animals for meat consumption and dairy cows for milk production. In the meantime, policymakers support increasing the consumption of lower-impact foods like cultivated meat and enriching the diet with plant proteins derived from cereal grains, legumes, potatoes, vegetables, and fruits.

### Investor disillusionment and financial struggles

About 150 startup companies are involved in unraveling the challenges of cultivated meat production. The oldest startup company started in 2016, and none of the startups have ever been profitable. It is almost inconceivable that venture capital companies and

large meatpackers like JBS, Tyson, and Cargill poured billions of dollars into cultivated meat startups based on little substantiated scientific information. Startups went out of their way claiming that the commercial market introduction of cultivated meat was just around the corner. This illusion was kept alive, knowing that many technological solutions were still waiting to be solved.

The reality in 2024 is that only a small fraction of the grand visions articulated in 2013—when the first US\$300,000 Mosa Meat burger was unveiled—have been realized. Even with a massive US\$1.6 billion in venture capital investments in 2021 and 2022, the anticipated market breakthroughs have not materialized. Instead, many of the more than 150 global cultured meat startups are facing contraction or even going out of business, casting doubt on the initial dreams of growing meat and fish from cells. In 2024, and likely in the years to come, venture capital is not some-

thing cultured meat companies can take for granted.

In 2024, very little real progress is made, and only a very few restaurants have limited amounts of cultivated meat on their menu at astronomically high prices. Moreover, the authentic-looking pieces of whole-cut chicken breast or chicken tenders are hybrid, i.e., a mix of pea and soy protein used as a scaffolding material for the tiny meat cell strands to grow on. Quantitatively speaking, at scale, the market introduction of cultivated meat isn't going to happen anytime soon. Anything before 2035 is simply wishful thinking. No wonder that some capital venture companies have become disillusioned about the exaggerated and missed timelines.

The slow progress—or better said, the no progress—of commercial market introduction has made quite a few capital venture companies realize that there will be no quick fix for the return on investment. Compared to the venture

capital boom of 2021 and 2022, it is estimated that 2024 will generate only a meager US\$36 million in new capital. This shift reflects changing sentiments in the world's food security landscape, which will not be as easily navigable as the founders of cultured meat companies initially preached. They are now looking elsewhere to make their investment dollars grow. This has caused a few cultivated meat startup companies to close their doors while many others scramble to get new capital.

The total global meat market stands at slightly over 50 billion kilograms (as of 2024). Even if all currently available cultured meat production facilities operate at full capacity, they would generate a maximum of 15 million kilograms—an extremely small fraction of what is required.

Transformative technology seldom follows a linear pathway, and real setbacks get in the way before actual advancements or solutions can be applied. At this

point, manufacturing cultivated meat is similar to making the impossible possible. Perhaps the true lesson that needs to be learned is for the startup companies to become more modest and stop making unsubstantiated claims about imminent commercial market introduction, selling at par with animal-grown meat, and toning down the environmental claims. Only then will there be a chance to change the current pessimism into a more positive outlook.

### The need for a unified sustainable meat ecosystem

The legislative authorities, the food industry, and its customers need an inclusive solution to unite and drive the world toward a more sustainable meat ecosystem. Cultivated meat is here to stay and is projected to break the monopoly of the traditional slaughter-based farming industry. Yet, in the cultured meat arena, hype and reality don't always see eye to eye simply because there are still many un-

knowns, with major engineering and technology challenges still needing to be resolved.

In many publications, cellular agriculture is positioned around the peak of inflated and lofty expectations or doom-scenario viewpoints that cultured meat will eventually blow up in a major disillusionment. Eventually, the outcome will probably be a plateau of scientific and technological progress when lasting infrastructure will become a sound supply for food security. Many stakeholders and consumers argue that plant-based meat alternatives, as well as cultivated meat, will be transitioning into market domination over conventionally raised and slaughtered meat. In the long run, these innovative foods are expected to perfectly fit the dietary lifestyle preferences of the young generations of consumers who also enjoy consuming plant-based meat products.

Cultivated meat is not “fake meat,” but rather real meat made

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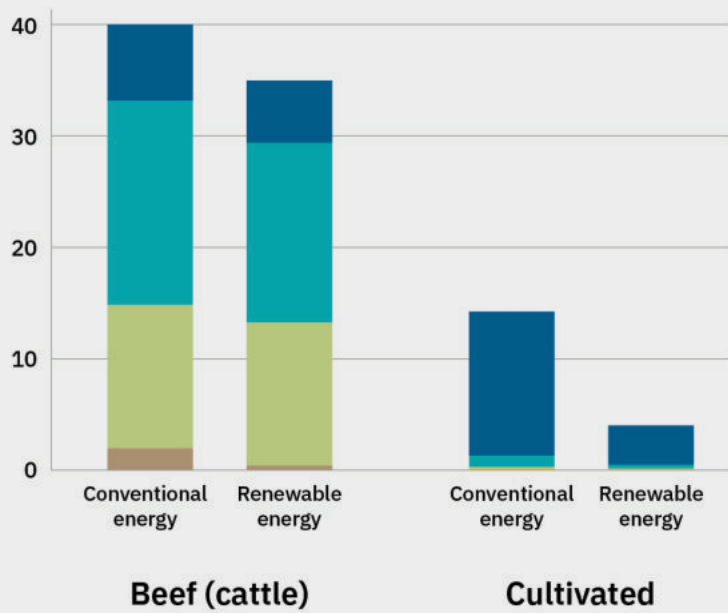
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(kg CO<sub>2</sub> eq/kg meat)

Carbon dioxide  
Methane  
Nitrous oxide  
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Data from Sinke *et al.* 2023.  
See study for the full set of assumptions.

The environmental impact of cultivated meats compared to conventional meats depends on several factors, particularly the energy sources used for the production facility and the ingredients for the growth medium. When fully renewable energy is used, cultivated meat's carbon footprint can compete with ambitious benchmarks of chicken and is lower than that of the other conventional meats. *Source: Sinke et al. 2023.*

from real cells from real animals. Cell-cultivated meat allows the manufacturing of high-quality protein without the need to feed, raise, and slaughter animals.

### Global rise in conventional livestock production

Conventional livestock production is increasing exponentially globally as more countries become more prosperous. Intensive livestock farming continues to lower costs,

making meat more affordable. Yet, the downside is the carbon footprint, which contributes to diverting crops to animal feed and climate change.

Although many world cultures and social traditions universally enjoy meat, UN and government policymakers believe it is time to switch from conventional slaughtered meat -which increasingly creates challenges for the environment- to a more humane method of meat production. The world's overreliance on factory-farmed livestock to feed the burgeoning demand for protein will be ecologically and environmentally difficult to sustain. There is also the misery of intensive meat production, often associated with chemical fertilizer, hormones, antibiotics, energy, land, and water required to keep the outgrowing cycle of animals at pace for an early arrival at the slaughterhouse. Suppose the technology-driven cultivated meat mission succeeds in displacing part of animal agriculture. In that case, it will significantly improve the environmental impact of food production, public health, animal ethics, and above all, food security in a world negatively affected by climate irregularities.

In a few words, cultivated meat is an emerging development with biotechnology, which aspires to grow meat from cells, preventing animal husbandry and slaughter. Growing steaks and coarse meat particles directly from non-genetically engineered animal cells makes the world better positioned to overcome food-related challenges and offer solutions to bring agricultural systems back into balance. Initially, the first entries of cell-cultivated meat started by using biomedical tissue-engineering technology to grow real animal cells without the animal. These slaughter-free meat products use around 90% less land, water, feed, and energy than conventional raised meat.

### Infrastructure needs for cultivated meat production

Looking at the current state of cultivated meat investments, it can be concluded that venture capitalists strongly believe that cultivated meat will be transformative and profitable as the world comes to grip with possible food insecurity and climate change. The regionalization or localization of cultivated meat is itself a way of carbon reduction. Especially venture capitalist

companies and startups are making bold pronouncements about the bright future of cell-cultivated meat. There are still many unanswered questions about cultivated meat technology.

To date, quite a few of the predictions seem to be based on wishful thinking. The uncertainty about the commercial launch of cultivated meat is related to the unknown technical challenges at the manufacturing scale and the intertwined cost-competitive nature. Some of these barriers are cell metabolism, sterility issues, thermodynamics, bioreactor design, medium costs, and optimum bioreactor volume capacity. All these variables ultimately need to be harmonized before cultivated meat can be produced to partly displace traditional slaughtered meat.

Many full-scale facilities need to be built if the production of cultivated meat is ever to become economical and technically feasible. Many thousand bioreactors will be needed to replace a small portion of the projected meat consumption. The estimated cost of these cultivation facilities and the cost of the growth media can be seen as a make-or-break issue for the future of the cultivated meat industry. As

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it stands now, venture capital companies will likely need to patiently wait for a meaningful return on investment, if ever. A more appropriate approach would be to consider these investments in relation to environmental and animal ethical or social considerations and financially supported by governments, for which return on investment is of secondary importance.

Food security, which most people living in developed countries take for granted, might only survive if a paradigm shift in next-generation technology is implemented.

Biomanufacturing of traditional foods such as meat and milk that are resource-intensive and expensive shows real potential to emerge as a lifesaver for future generations. Cheap and accessible cultivated protein -including mycelium or fungi varieties- will need forward-thinking implementation based on science and entrepreneurial spirit. To be frank and honest, like with any other revolutionary concept, only time will tell if these

technologies rise as a salvation or sink as an expensive financial disaster.

### The investor's perspective on cellular agriculture

It is incredible to see that the very first cell ag companies, which were founded in 2014, have already reached an astounding 150+ startups in 2024, employing thousands of cell ag scientists around the globe. Cultivated meat startup companies are still quite far from actively displacing animal agriculture. Unfortunately, the downside of this emerging industry is that most, if not all of these companies are working within their own confinement with minimal sharing of ideas. These attitudes inevitably slow down speed-to-market due to a lack of foundational knowledge and common interest frameworks that may trigger new ideas for researchers, such as—for example—accessible cell-line banks.

The best method to grow cultivated meat cells is still surrounded

by company proprietary information and secrecy. There are still quite a few unanswered questions, especially regarding information about cell density, cell lines, and technical bottlenecks that need to be overcome. Bacteria and viruses may present issues of their own. Cultured cells have no immune system. Thus, there is a risk that both bacteria and viruses can spoil or contaminate the biomass.

The due diligence trajectory for investors should focus on five critical topics:

- The selection of the growth media
- Hardware for optimized capacity bioreactors and scalability
- R&D: internal or open-source
- Commercial speed to market
- Return on Investment for venture capital companies

In principle, all types of meat can be cultivated: beef, pork, turkey, chicken, and fish. As a matter of fact, once the cultivated-meat science and engineering technology is ready for large up-scaling,

cost efficiencies will hopefully become economically competitive, allowing the production of a nutritionally superior lean and tasty protein source. Before that happens, the road to success will be difficult to navigate, with many foreseen and unforeseen obstacles. It is fair to say that the true cost of traditional meat is estimated to be far higher than retail store pricing if the hidden costs of farm subsidy programs and greenhouse gas emissions are taken into consideration. In terms of sustainability, cultivated meat has the potential to significantly reduce the environmental footprint of meat production.

### The technical challenges of scaling cultivated meat

Muscle and fat cell maturation will take a combination of advanced cell sources, serum-free culture media formulations, and edible (gelatin or soy protein or pea protein) scaffolds to form the network for growing cells, as well as engineering

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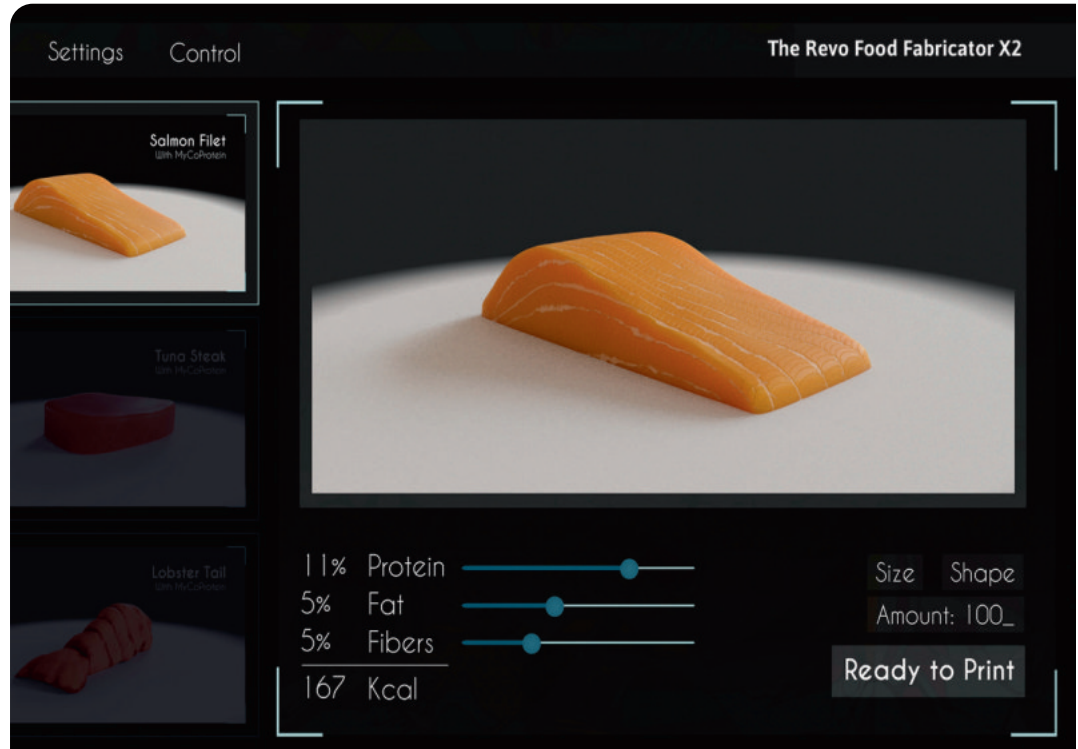


advances in a bioreactor design technology. Making tissue-engineered cultivated meat and cultivated fish at scale is now considered the biggest roadblock hindering a rapid introduction of commercial quantities. The biopharmaceutical industry's largest designed bioreactors tend to peak at around 25,000 liters. Anything larger than that takes the engineering of these vats in uncharted territory, the biggest problem of which will be to provide all the cells with the same amount of nutrients and oxygen. The slow-stirring blades may potentially damage the fragile cells, which will make them useless. As it stands today, a 25,000-liter capacity bioreactor seems the most efficient equipment to commercially grow meat. However, the size of bioreactors will ultimately need to reach a minimum 100,000-liter capacity, though the industry already talks about 250,000-liter sizes. The engineering of these gigantic bioreactors will go into uncharted territory without any experience to fall back on.

Driving down the costs of the media nutrient ingredients used to cultivate meat is the main challenge to make the new industry profitable. For that to happen, the key is to continually find more efficient cells and specially formulated growth medium to jump-start cell growth. This medium is a nutrient-dense broth of purified water, glucose, salts, amino acids, and growth factors such as recombinant proteins, cytokines, hormones, and some other additives that regulate cell development and metabolism. (All substances present in the medium can be compared to the function of blood that provides nutrients and hormones to the living cells in a body.)

Once the initial inoculation phase is completed, the cells will slowly start to multiply, and the activated cells are transferred to a small donor 50-liter bioreactor. After a 10-day growing time, the substrates are transferred to a large bioreactor while maintaining a specific ratio of fluid to cells to optimize metabolic requirements.

In cultured meat production, sterility is of utmost importance. Bacterial infection or contamination can happen in just a few hours, which renders the entire batch useless. To avoid these potential weak hurdles, it will be essen-



In October, Revo Foods opened the world's largest industrial facility for 3D-printed foods. At total capacity, the facility produces up to 60 tonnes per month, the Austrian-based company claims. *Photo: Revo Foods*

tial to design and operate pharmaceutical-grade cultivated-meat clean processing rooms. These aseptic production methods are another cost that comes into play to calculate the real costs of cultured meat production.

### Balancing ambition with reality in the alt protein space

Alternatives to animal protein products and ingredients, whether through plant-based formulations or cellular agriculture, including precision fermentation, continue to attract investors. The stakes are astronomically high. For example, cell-cultured meat will have a shot to capture a yet undefined share of the US\$1.4 trillion animal meat market. The hypothesis is no longer a fantasy when looking at the US milk market, where some 15% of milk products are already captured by plant milk. It is plausible that the same will happen to the cell-cultivated meat and -fish market.

Since 2011, the Eat Just startup company has raised about US\$850 million, making it one of the best financially backed in plant-based alternatives like vegan mayonnaise as well as cultivated chicken via their Good Meat subsidiary. Eat

Just has backing from, among others, Qatar Investment Authority, UBS, and Charlesbank Capital Partners. The verdict is still out, but either strategic financial mismanagement or too aggressive and unproven technology growing projections have become a major wake-up call for the many other startups that are embarking on commercializing cultivated meat.

For example, engineering solutions provider ABEC was appointed by Good Meat (the cultivated meat division of Eat Just) to design, manufacture, install, and commission a gigantic 250,000-liter bioreactor in the US and Singapore. The capacity of this bioreactor to produce avian and mammalian cell-based meat will be about 15,000 metric tons of slaughter-free meat. This decision was probably based on wishful thinking rather than developing bioreactors that hold just hundreds or thousands of liters to grow animal cells. It would have been a smarter idea to gradually grow the cultivated meat technology using a bioreactor that is priced somewhere between US\$150 million and US\$200 million. Such a strategy looks more viable long-term.

### A reality check for the cultivated meat industry

The first commercially operated bioreactor started production in 2023 by Upside Foods (Emeryville, CA) and Eat Just (Singapore). However, the Upside Foods EPIC facility is in 2024 still being used as an experimental pilot plant with little real quantities of cultivated meat to show for.

JBS, the Brazilian powerhouse and largest protein producer in the world, is constructing a cultivated beef facility in San Sebastian, Spain. Reportedly, the facility will be fully operational by mid-2024. The necessary technology impetus will be provided by BioTech Foods, in which JBS holds a 53% ownership stake. The new Sebastian production facility will cover an area of 20,000 square meters.

Financial backing by venture capitalists and legacy food companies is now allowing many startups to transition into pilot scale-up and even commercialization of cell-based meat. For cultured meat startups and investors alike, the successful outcome is still based on taking informed bets to make the technology work and pay off. For 2024, a certain hesitance is developing into further financing or invest-



ing in cultivated meat startups. Perhaps venture capital companies are now in a wait-and-see mode, and/or a saturation point has been reached.

The first signs of a significant market contraction among startups are not encouraging. SCiFi Foods in San Francisco, CA, permanently closed its doors in June 2024. New Age Meat closed earlier, and Berkeley, CA-based Upside Foods laid off research and equipment specialists. Aleph Farms in Israel also laid off about 30% of its workforce. These companies, along with several others, cited the challenging funding environment as the primary reason for their struggles, making it difficult to stay afloat, let alone build a commercial facility for cultured meat production.

It is plausible that many of the cultivated meat startups will be entering the road of consolidation. It is no secret that biotechnology food startups are increasingly challenged in 2024 to generate new funding opportunities. Of the many cultivated meat startups, the top five account for almost 50% of the total venture capital investments: Upside Foods, Mosa Meat, Believer Meats, Aleph Farms, and Wildtype. Cultivated meat startups raised 34% less capital in 2022 and 2021.

2024 is proving to be a tough year for most biotech food startups to raise capital, turning the once-promising dreams into a frustratingly difficult reality.

Cultured meat startups are still grappling with the complexities of growing meat in a bioreactor, particularly with overcoming massive technological and engineering challenges. A major issue remains the search to increase cell density per unit of bioreactor volume. Companies like Upside Foods, Eat Just, and Mosa Meat are working on improving the efficiency of growth media and choosing the right engineering systems. These are critical concerns since producing growth media is expensive.

### Overcoming consumer perception and adoption

The consumers' minds about food are unpredictable, and logic fails at times. Food is different from everything else because it is surrounded by much subjectivity and irrational behavior. Justifying behavior is often easier than changing behav-

ior. Despite all the publicity around the need to reduce meat consumption, it is weird to conclude that overall, consumers do not eat less meat and fish even if they have increasing concerns over animal welfare and health issues. Eating meat is thoroughly ingrained in most cultures. When moral standards and self-serving desires come into conflict, the consumers' self-interest often wins to justify their lifestyle. Psychologically speaking, people tend to justify their behavior rather than change it when they feel guilty.

Hopefully, prices of cultured meat and fish will be at par or even better than traditionally farmed animal meat or ocean-caught fish and crustaceans like lobster. As these technologies progress with scale and high-volume output bioreactors, prices will continue to drop, and cultivated meat and fish will become more affordable. It is also likely that cultivated meat or -fish will team up with plant protein components as true hybrid foods to further reduce costs and improve its environmental status while perfectly mimicking its meat- or fish-eating experience.

The under-30-year-old generation of customers takes more responsibility for factory farming and slaughtering. The Western world has clearly come to a T-junction where it is being pushed to decide on which way to go -- either stay the course of conventional meat production or embrace sustainable cultivated meat.

For consumers to accept cultivated meat, branding will be key, and reframing words and explaining the science will be essential. Sustainability issues will play an important role in changing the perception from traditional killed animals for meat procurement to "bio-fabricated synthetic" or "cell-cultivated" meat. The idea of growing animal cells at scale inside a bioreactor is still something that ordinary people will find hard to grasp. Mainstream acceptance of cell-cultivated meat is still mainly based on assumptions and hypothetical arguments. Going forward, it is a long shot but certainly plausible that sustainable consumption of cell-cultivated meat will be the main competitor to livestock-harvested products, creating a balance that slowly but surely tilts in favor of cell-cultivated meat as

new generations of consumers adapt to the new paradigms.

### The main drivers for cost reductions

The cultured meat race toward achieving price parity with conventional meat may begin as soon as 2035. However, it is not unlikely that parity pricing will be reached until 2040. The three main technological drivers of cultured meat cost reductions are:

- Large scale bioreactor vessels
- Growth media
- Cell density

Going forward, it is expected that innovative single-cell fermentation-based growth medium proteins will significantly reduce costs for cultured meat production. The goal is to produce cultivated meat by using a cell-feed that is a completely animal-free component. In principle, cell feed is the nutrient component that cells need to multiply in a similar fashion to how they would inside an animal. Animal-free component cells are a major depar-

ture from using fetal bovine serum, and its elimination brings emotional and ethical benefits for consumers.

Although there is still a long journey from research to the plate, the global debate on many simultaneously driven issues like the reduction of greenhouse gases and loss of biodiversity will work as a favorable perfect storm for cultivated meat, a journey that will not be entirely smooth sailing. For example, ramping up cultivated meat production will also mean ramping up the global production of individual amino acids to support medium components needed by the cultivated meat industry. Surely, these amino acids can be extracted from soy or pea crops, though that would stress the destructive monocrop culture even further into negative territory. After all, the massive production of grains and pulses is one of the primary drivers of deforestation and biodiversity loss in the world. Soy is often seen as one of the most destructive

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## Biomass hype or reality?



In May, GOOD Meat launched the world's first cultivated meat product sold at retail in Huber's Butchery, Singapore. The chicken contains only 3% animal cells, with the remaining 97% made of plant protein. Scalability and price remain key challenges for the emerging cellular agriculture industry, but this launch marks a significant step towards making cultivated meat more accessible and affordable. Photo: IMAGO/Dreamstime

monoculture crops in agriculture, contributing to climate change because of tropical deforestation, water pollution, and eradication of wildlife.

### Regulatory challenges and legislative pushback

Traditional livestock farmers do not have to worry about competition from cell-cultured meat companies. There are clear FAO forecasts that global meat production needs to increase by 50% to provide quality protein for the 10 billion people living on planet Earth by 2050. If 100% of that growth were cell-based meat, it would not impact a single livestock producer anywhere on the planet.

Like with any other disrupting innovation, there is a measured pushback from the legacy industry for fear that their "monopoly" business model might be threatened. Eventually, the implementation of new technology needed by the global market will win due to the numerous socioeconomic, health, and food security issues. History has always shown that progress can be temporarily slowed down, but it ultimately will succeed. Hence, the big-name traditional meat processors will eventually embrace cell-cultivated meat

and -fish, whether as acquirers, licensees, customers, or investors.

It is not surprising that the traditional and legacy meat producers seem to "fight" a war on two fronts simultaneously: the emerging cultivated meat and cultivated fish products finding themselves cornered or even wasted by the huge influence of plant meat products. As a strategy, the traditional meat industry stresses the fact that meat has a "clean deck", meaning that it contains only one ingredient. For reference, they compare it with the plant-based meat alternative products that are formulated using a long list of ingredients, including chemical-sounding names like methylcellulose and many more. Expectedly, the companies of plant meat foods will rightfully answer by stating that meat is also a combination of many individual components to grow to the point that it can be eaten.

Even though the FDA / USDA has approved cultivated meat to be sold by Upside Foods and Good Meat, there is still (unexpected) major opposition by a US State going so far as to criminalize the production, sale, or consumption of cultivated meat. A case in point is Florida, which introduced two legislative bills in February 2024

that could significantly impact the availability of cultivated meat within the State. Arizona might be the next state to require strict legislation on product labeling. The verdict is still out, though by means of restrictive legislation, these actions have a direct impact on protein biotech research, which will be needed to feed and nourish the growing world population.

### Startups lead the charge in cultivated meat innovation

There is nothing unreal about cell-cultured meat. Cultured meat is analogous to "clean energy" and will help the food industry avoid not only ballooning costs of grain and water but also waste disposal associated with livestock while significantly reducing emissions of greenhouse gases.

Several startups claim that they are in the final stages of scaling up their slaughter-free meat and catch-free seafood while offering precision fermentation capabilities and technologies. The future is approaching faster than many people like to think. Aleph Farms, Upside Foods, Mosa Meat, and Shiok Meat are planning to start the initial commercial sales of cultivated meat and cultivated fish.

Mosa Meat (Netherlands) opened

in May 2023 their first 2750 sq/mt pilot production facility for cultivated burgers. Singapore is their first export market because sales of cultivated meat are already cleared. The "Mosa burger" is a true hybrid food containing about 65% cell-cultivated lean beef and beef fat, and the remaining 35% is made up of soy protein components.

Switzerland's largest supermarket, Migros, signed an agreement with SuperMeat (Israel) in August 2022 to develop a European infrastructure to produce and market cell-based meat. It is likely that Migros will likely be the first European supermarket to sell its own brand of cultivated meat on a broad commercial scale.

Pending USDA-FSIS regulatory review and approval, Upside Foods is planning to introduce cell-based cultured chicken in 2025. This move will showcase its innovative meat cultivation abilities at its Emeryville, CA EPIC Center (Engineering, Production, and Innovation Center), with a projected annual capacity of about 180 metric tons. Upside Foods is more than cultured beef. Its January 2022 acquisition of Cultured Decadence (Madison, WI) was dedicated to cultivated seafood products such as lobsters and other crustaceans.

Cultivated meat producer Believer Meats (previously known as Future Meat Technologies) will open its first full-scale production facility in Wilson, North Carolina, in the first quarter of 2024. The 20,500 sqm facility will be designed to process at least 10,000 metric tons of cultivated meat per year.

Not to be outdone, the idea is taking root that Aleph Farms (Israel) and Fermbox Bio plan to build their first cell-based meat production facility in Thailand. The reason is that, most likely, the EMEA and APAC countries will initially become the largest markets for cultivated meat. Both regions project a continuation of increasing demand for animal-based proteins and fat, whose products ensure short and predictable value chains.

The Eat Just company is committed to building a large-scale cultivated meat facility in Singapore and Qatar. For reference, the Singapore-based pilot facility of the Eat Just Food company currently uses a 1,200-liter reactor capable of producing a few hundred kilos of cultured chicken meat per year.



The products will be commercially available in small quantities at select restaurants under the GOOD meat label. Singapore has already been given regulatory approval, and it is likely that the Ministry of Public Health in Qatar will grant regulatory approval soon. Clearly, countries that traditionally rely on food imports now choose to go through a rapid transition to achieving self-sufficiency across many food sectors, including animal-free precision fermented dairy protein ingredients such as whey protein and casein protein.

Startup Believer Meat (Wilson NC) has teamed up with global powerhouse Nestle Research with all signs showing “Go” and hopefully will speed up the time to market at par or lower prices than conventionally slaughtered meat. In the meantime, authentic-looking 3D bioprinted plant-based meat will likely be infused with cultivated meat and, hence, can be considered a true hybrid food product.

MeaTech 3D, a startup from Israel, is creating alternatives to industrialized animal farming by developing its proprietary cell-based meat products made by 3D tissue engineering and bio-printing principles, as well as various types of cultured fat for plant meat or hybrid meat alternatives.

### A pragmatic solution for cultivated meat

Making larger volumes of cultivated meat at low cost is one of the remaining hurdles for the emerging industry. How much can affordable cultivated meat make a dent in the more than US\$1.4 trillion global meat market? At best, the current outlook for cultivated meat is going the hybrid route, i.e., mixing animal meat and fat cells with plant protein ingredients—most of which are extruded—into tasty and nutritious food products. Meat hybrids can be defined as blends combining traditional animal-raised meat and/or cultivated meat, as well as plant protein sources. Blending familiar sources with unfamiliar sources will help create a lower barrier of entry for consumers and thus support the expanding alt-protein markets.

These products are easier to make because the cultivated cells grown in a bioreactor can be made

as a slurry that is easy to blend with plant protein ingredients. Combining cultivated meat with plant protein ingredients will create hybrid products to draw consumers to the preferred taste and texture of these alternative food products made available at competitive pricing. Hybrid-formulated approaches could move the alternative protein category forward faster. Using plant-based ingredients generally allows lower-end food costs when integrated with fermentation-derived or cultivated meat components.

For example, a burger or chicken nugget formulation containing as little as 5% cultivated meat can significantly enhance all organoleptic properties while boosting the value of plant protein sources beyond what they can achieve alone. These types of hybrid products are already commercially available and are being produced in small quantities by Eat Just at select restaurants in Singapore.

These combinations of plant-based and cultured meat will most likely become available as beef burgers and chicken nuggets, then gradually diversify into incremental, more premium products that are able to mimic the meat-eating experience. These hybrid products will be significantly more affordable than cultivated meat alone. Especially battered and breaded products such as chicken nuggets can be produced at considerably low costs.

Cultured meat embedded in a blend of plant protein, fat, and water, surrounded by hydrated extruded plant protein, should not be viewed as a compromise of the early cultured meat visionaries. Instead, it represents a significant step forward in marketing hybrid meat products as an essential part of making nutritious, healthy, affordable, and great-tasting food options available and sustainable.

When you think of it, hybrid products are really nothing new. Cultivated meat only replaces the animal meat source in these products, whereas all other inclusions like textured plant protein are used to mimic traditional meat products like chicken nuggets while significantly reducing costs. These hybrid products have been hugely successful for many years, and many millions of them are sold by the world's largest fast-food compa-

nies. One could think about the McDo Burger, a fixture on the McDonald's menu board in the Philippines since 1994. This best-selling hybrid burger contains only some 30% beef and many more spin-off products formulated using chicken, pork, or fish.

### Protein migration—cultivated meat going forward

Looking at all cultivated meat activities, one might wonder if most press announcements are based on reality or wishful thinking. Can consumers indeed eat their way out of climate change, or is the cultivated meat industry a fantasy that is doomed to fail? The fact is that the speed of market introduction will be very slow and at high prices that only the happy few can afford. Realistically speaking, not much will happen before 2030, and only then when the emerging cultivated meat business is financially supported by either steep government subsidies or a continuation of venture capital investments. At the time of this

writing, dark clouds have appeared, and the wait is for unbiased information on when the meat-protein transition will happen.

Most likely, kilo-for-kilo cultivated meat is probably too expensive and initially will only displace a modest, very small percentage of the trillion-dollar global meat industry. It can also be assumed that future meat prices—especially for beef—will eventually become higher as resources like feed, land, and water become more scarce. Relatively speaking, as the price of animal meat goes up, the relative price of cultured meat will come down.



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